Coupled Tropical Cyclone-Ocean Modeling for Transition to Operational Predictive Capabilities

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LONG-TERM GOAL

Our long term fundamental goals are 1) to better understand the interaction between the ocean and tropical cyclones using numerical simulation models, and 2) to investigate the operational capability of coupled tropical cyclone-ocean models in predicting the ocean response and tropical cyclone movement and intensity.

OBJECTIVES

- Development of a coupled hurricane-ocean experimental prediction system for the North Atlantic.
- Improved ocean model initialization and data assimilation techniques for forecast modeling.
- Development of a movable grid multi-nested ocean model.

APPROACH

Our tools for this work are high-resolution ocean and tropical cyclone models used in either coupled or uncoupled configurations. We currently employ two ocean models and two tropical cyclone models. The first ocean model we use is the Princeton Ocean Model (POM). We have used the POM for the Atlantic region and we plan to continue to use it for this area for the near future. Our newly developed movable nested grid ocean model (Ginis et al. 1998, Rowley and Ginis 1999) is the second ocean model. The major feature of the model is its multiply-nested, movable mesh configuration, which is capable of depicting the ocean response with high resolution underneath the tropical cyclone.

We employ one of the premier tropical cyclone forecast systems, the GFDL model, which was adopted as the official operational hurricane prediction model at the National Weather Service starting with the 1995 hurricane season. This model (known as the GFDN) is also run operationally for the western Pacific at Fleet Numerical (FNMOC) in support of the Joint Typhoon Warning Center (JTWC). The second tropical cyclone model we use is specifically designed for simulations of binary storm interactions (Falkovich et al. 1995).

Accomplishments during the currently funded ONR project:

1. Design, development and analysis of a real-time coupled hurricane-ocean forecast system in the North Atlantic and investigations of the effect of ocean coupling on tropical cyclones.

2. Development of a movable nested-mesh ocean model applicable for both the open ocean and littoral zones around continents.

3. Design and testing of a coupled tropical cyclone-ocean model for the western Pacific.

4. Design data assimilation and model initialization techniques for the Gulf Stream system.

5. Identify the effects of ocean coupling on the regimes of binary storm interactions.

RESULTS

a. *Implementation and testing a real-time coupled hurricane-ocean experimental prediction system for the North Atlantic* (This work was also partially supported by an NSF/NOAA grant)

We have made a successful conversion of our coupled hurricane-ocean system from a hindcast research model performing simulations on a case-by-case basis, to a fully automated real-time prediction system that successfully produced more than 140 forecasts during the 1998 Atlantic hurricane season (Ginis et al, 1999). The coupled forecast system was implemented on the NAVOCEANO MSRC Cray T90 under the auspices of the DoD High Performance Computing Modernization Program, where all hurricane forecasts were made. A direct link between NAVO and NOAA/NCEP was established to transfer the initial fields and output of the GFDL hurricane model that is run operationally at NCEP. The coupled model results were made available to the National Hurricane Center via a dedicated web site (**http://seip.gso.uri.edu/tropcyc**). The ocean component of the coupled system, the POM, was enhanced by introducing multiple computational domains in the North Atlantic basin treated by the system, and by improving the ocean model initialization. The coupled system improved the average intensity prediction more than 26% in comparison with the operational (uncoupled) GFDL model (Figure 1). Due to this success, NCEP has made a decision to run our coupled model in parallel with the operational GFDL model on the NCEP system during the 1999 hurricane season. If the model continues to demonstrate superior performance, it will become the first operational coupled air-sea interaction model at the National Weather Service, starting in the year 2000.

b. *Development of a movable nested-mesh primitive equation model*

We continued development of a new movable nested-mesh ocean model (Ginis et al, 1998, Rowley and Ginis, 1999). This model has several potential advantages over the POM that we have been using in the GFDL/URI coupled tropical cyclone-ocean system discussed above. The major advantage is the use of the movable nested-mesh structure to conserve computational time and memory. This is achieved by allowing the inner meshes to follow the simulated oceanic/atmospheric features, thus using the high horizontal resolution only where it is most needed. The nested system is fully relocatable and can be introduced at any geographical location at any time. We have recently added two important capabilities to the model: a barotropic mode with bottom topography and the ability for the movable inner meshes to cross coastlines.

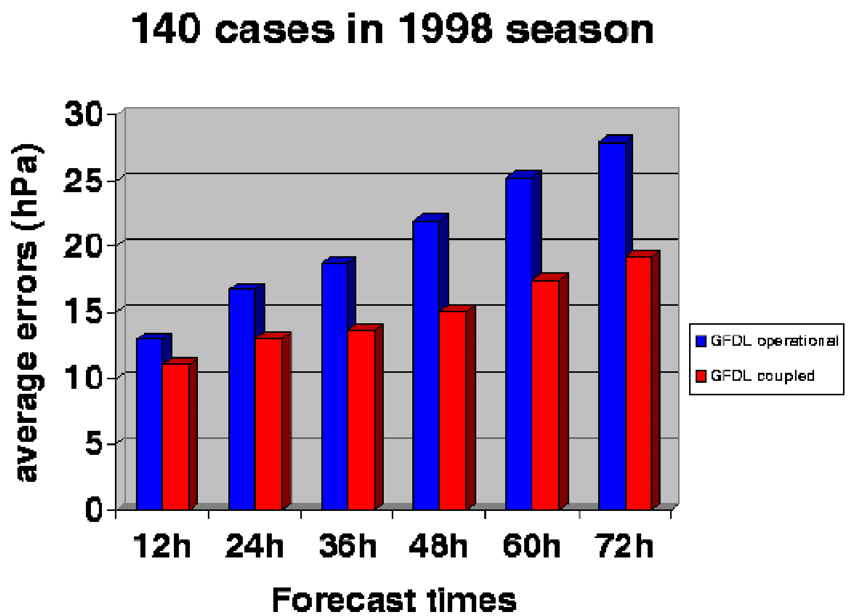

Fig. 1 A summary of the minimum central pressure intensity forecast errors for the coupled and operational (uncoupled) models for 12-hourly forecast intervals in the 1998 hurricane season.

The new model features for treating coastlines and bottom topography in all meshes make it fully configurable for coastal modeling. An example of the numerical simulation of Typhoon Niki in 1996 making landfall in southeast Asia. is shown in Figure 2. The difference in coastline position at different mesh resolutions is evident.

c. *Development of a coupled tropical cyclone—ocean model in the western North Pacific*

The URI movable mesh model has been successfully coupled with the Navy's version of the GFDL tropical cyclone model (GFDN), and some idealized and real-case simulations in the western Pacific have been performed. The real-case simulations use data provided to us by FNMOC for 14 GFDN forecasts for Typhoon Babs in 1998. These data include the GFDN model initialization and boundary conditions from the NOGAPS global analysis and forecast, and auxiliary files describing the typhoon vortex at the time of the forecast. Analyses of the model results are in progress. This work was conducted in coordination with FNMOC and built directly upon our successful joint GFDL/URI coupled model research program.

IMPACT/APPLICATION

The results of this study indicate that the present tropical cyclone forecast system at FNMOC utilizing NOGAPS and GFDN is deficient in its inadequate description of the evolution of the subsurface ocean, and that including ocean coupling will greatly improve tropical cyclone intensity forecasting and therefore provide a better numerical guidance product for the JTWC.

The new movable grid ocean model makes it feasible to combine realistic global or basin-scale ocean simulations with mesoscale forecasts for selected regions. The nested grid model may be may be utilized as the ocean component of the coupled ocean atmosphere mesoscale prediction system (COAMPS) which is being developed at the Naval Research Laboratory, Marine Meteorology Division, Monterey, CA.

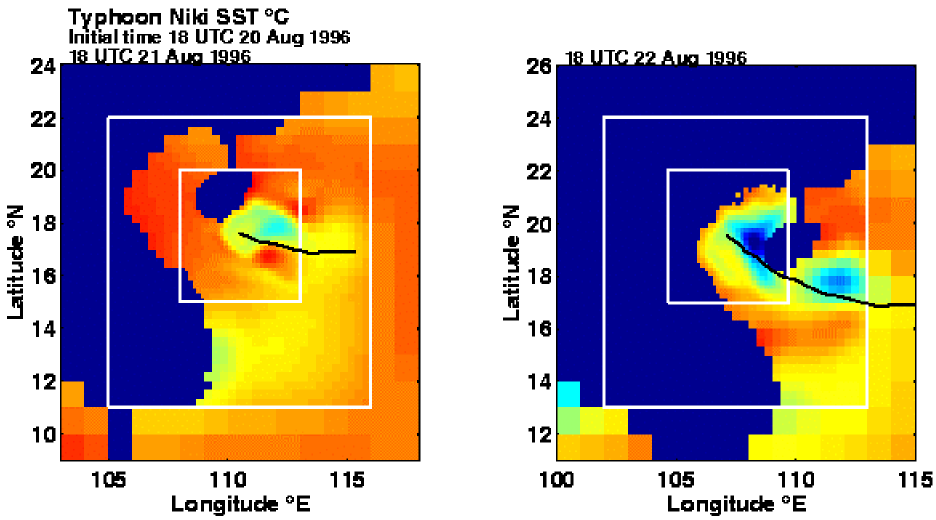

Fig. 2. Sea surface temperature response to Typhoon Niki as simulated by the URI movable nested mesh ocean model.

TRANSITIONS

It is expected that the results of this project will be used by the National Weather Service and Navy for operational purposes. It is also hoped that the nested-grid ocean model developed during this project will add to the utility of COAMPS as it transitions to operational use over the next few years.

RELATED PROJECTS

This research is closely related to other research projects funded by ONR that study tropical cyclones and the ocean response to tropical cyclone forcing. We are working in close collaboration with atmospheric scientists in developing and testing coupled tropical cyclone-ocean models: Dr. Tuleya and his group at the NOAA Geophysical Fluid Dynamics Laboratory; and Prof. Khain and his group at the Hebrew University of Jerusalem. Implementation and testing of the coupled hurricane-ocean system at FNMOC will be conducted in collaboration with Dr. Mary Alice Rennick.

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